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Comparison of the Outcomes of Endoscopic Posterolateral Interbody Fusion and Lateral Interbody Fusion in the Treatment of Lumbar Degenerative Disease: A Systematic Review and Network Meta-Analysis

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ABSTRACT

Objective: Although endoscopic technologies have been increasingly applied in lumbar fusion surgery in recent years, the advantages and disadvantages of endoscopic posterolateral fusion compared with lateral fusion remain unclear. Six different single-level lumbar interbody fusion procedures were compared to determine whether indirect decompression fusion could achieve levels of efficacy and safety comparable to those of minimally invasive direct decompression fusion in the treatment of lumbar degenerative disease (LDD).

Method: A literature search was conducted in the PubMed, Embase, and Cochrane Library databases, and studies on the treatment of LDD published from 2004 to March 2024 were retrieved. The data of preset clinical outcome measures, including operation time, intraoperative estimated blood loss (EBL), length of hospital stay (LOS), complications, visual analog scale (VAS) score, and the Oswestry Disability Index (ODI), were extracted from the studies.

Results: Thirty-five studies with 3467 patients were included in this review. Network meta-analysis revealed no significant differences in improvements in pain and disability or adverse events among the procedures, except for uniportal endoscopic lumbar interbody fusion (UELIF), which resulted in a lower degree of improvement in the ODI than oblique lateral interbody fusion (OLIF). Stand-alone lateral lumbar interbody fusion (SA-LLIF) exhibited the best performance in terms of indicators of early efficacy, such as surgical time and LOS. OLIF and SA-LLIF had higher fusion rates than did UELIF and minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF). MIS-TLIF resulted in greater EBL than did OLIF, SA-LLIF, and UELIF.

Conclusion: Minimally invasive lumbar interbody fusion achieves good therapeutic results in LDD patients regardless of the use of indirect or direct decompression, whereas SA-LLIF has better early efficacy.

Xijian Hu, Lei Yan, and Jing Chai are co-first authors.

1 | Introduction

Decompression is an important step in lumbar interbody fusion to relieve nerve compression and can be categorized into direct and indirect decompression. Traditional posterolateral approach procedures, such as posterior lumbar interbody fusion (PLIF) [1] and transforaminal lumbar interbody fusion (TLIF) [2], involve the resection of some of the tissues of the spinal canal as part of direct decompression; however, damage to the posterior anatomical structure of the spine is substantial, bleeding is high, the nerve is manipulated for an extended period during the operation, and the postoperative bed rest time is long, during which the patient is likely to develop complications that affect therapeutic efficacy [1, 3].

Indirect decompression was proposed many years ago with the invention of anterior lumbar interbody fusion (ALIF), and the lateral lumbar interbody fusion (LLIF) procedure, a new approach with wider indications developed in recent years, has increased the popularity of ALIF. LLIF includes extreme/direct lateral lumbar interbody fusion (X/DLIF) via the transpsoas approach and oblique lateral lumbar interbody fusion (OLIF) via the prepsoas approach [4, 5]. By expanding the intervertebral space, the height of the intervertebral foramen is increased, and the ligamentum flavum in the spinal canal is retracted to achieve indirect decompression. Stand-alone lateral lumbar interbody fusion (SA-LLIF) is a less time-consuming and less invasive procedure than instrument-based LLIF. However, SA-LLIF has a low fusion rate and a high reoperation rate, and the risk of cage subsidence needs to be carefully assessed preoperatively [6, 7]. In recent years, the advancement and popularization of minimally invasive surgical techniques have led to the emergence of minimally invasive transforaminal lumbar interbody fusion (MIS-TLIF) and endoscopic lumbar interbody fusion (ELIF). ELIF combined with percutaneous pedicle screw (PPS) fixation is a modified protocol for posterolateral approach fusion that has the advantages of reduced tissue damage and a shorter postoperative recovery time [8, 9]. Currently, the name of the ELIF procedure has not yet been standardized; in this study, ELIF was classified according to the number of channels: uniportal endoscopic lumbar interbody fusion (UELIF); typical procedures, including percutaneous endoscopic lumbar interbody fusion (PELIF) and full-endoscopic lumbar interbody fusion (FELIF); and biportal endoscopic lumbar interbody fusion (BELIF), which is dominated by unilateral biportal endoscopic lumbar interbody fusion (UBELIF/ULIF).

A review of the literature revealed that most clinical studies of ELIF involve single-segment surgery. However, currently, the only meta-analysis that compared ELIF and LLIF did not include a strict limit on the number of operated segments (i.e., ≤ 3) as part of the inclusion criteria [10], which may have led to additional heterogeneity in the results of the study. In addition, the most minimally invasive indirect decompression method for lumbar interbody fusion, SA-LLIF, has not been used as an independent intervention for comparison with ELIF in evidence-based medical studies, and the advantages and disadvantages of the two methods warrant further investigation.

The purpose of this study was to compare the clinical outcomes, complications, and fusion rates between indirect and direct decompression fusion in the treatment of lumbar degenerative disease (LDD) with single-segment surgery to minimize the influence of segmental differences.

2 | Methods

In this study, evidence selection, qualitative synthesis, and meta-analysis were performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Assessing the Methodological Quality of Systematic Reviews (AMSTAR) guidelines. The study protocol was registered on the International Prospective Register of Systematic Reviews (PROSPERO, CRD 42024552428).

2.1 | Brief Description and Definition of Surgical Techniques

A brief explanation of each procedure is provided in Figure 1. (1) X/DLIF: The patient was positioned in the right or left decubitus

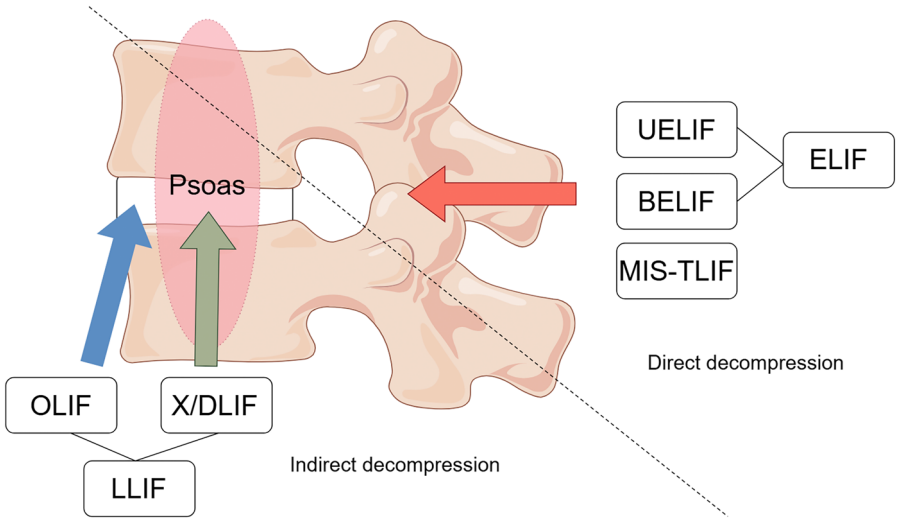

FIGURE 1 | Operation classification and approach differences.

position. After the external oblique muscle, internal oblique muscle, and transversalis fascia were dissected, the psoas muscle was identified and split. Discectomy, end plate preparation and cage insertion were performed. The patient was repositioned in the prone position to perform the internal fixation procedure, and bilateral PPSF was the most common method of internal fixation. (2) OLIF: The OLIF procedure is similar to X/DLIF, with the main difference being the disposal of the psoas muscle. In the retroperitoneal space, surgeons perform blunt dissection through the plane between the retroperitoneal fat and psoas muscle to access the lumbar spine while protecting both the psoas muscle and the plexus. (3) SA-LLIF: X/DLIF and OLIF procedures without internal fixation. (4) MIS-TLIF: The patient underwent surgery in the prone position. The procedures included hemilaminectomy, medial facetectomy, ligamentum flavum removal on the approach side, discectomy, and endplate preparation. Then, the interbody cage was inserted. Finally, the pedicle screw was placed percutaneously or via the Wiltse approach. (5) UELIF: The patient underwent surgery in the prone position. A spinal needle was inserted and navigated toward the intervertebral foramen under an image intensifier from the skin entry point and then replaced by a guidewire. After traditional guidewire/rod replacement and further graded tissue dilation, a working tube was introduced at the appropriate position, and nerve root decompression, annulus opening, nucleus pulposus removal and cage insertion were performed under endoscopic views. A bilateral PPS was used for internal fixation. (6) BELIF: The surgical procedure was similar to that of UELIF, with the greatest difference being that BELIF involves the establishment of two channels above and below the target segment for observation and operation, respectively. The major differences among the procedures are shown in Table 1.

2.2 | Definitions of the Outcomes

The degree of improvement in clinical symptoms in LDD patients after surgery was calculated as the difference between the visual analog scale (VAS) and Oswestry Disability Index (ODI) scores before and at the last postoperative follow-up. These two scoring systems are used to evaluate pain and dysfunction, respectively, and are commonly used outcomes in related studies. In this study, the primary outcomes were as follows: (1) the change in VAS-leg pain score (VAS-LP change); (2) the change in VAS-back pain score (VAS-BP change); and (3) the change in ODI score (ODI change). Since the above indicators must be observed in a long-term follow-up, we set the follow-up time to 12 months or longer.

Secondary outcomes: (1) Adverse events (AE), all clinical and imaging AEs after surgery were included, and the number of AE with clinical symptoms was calculated and divided by the sample size to analyze the incidence of clinical complications; (2) estimated blood loss (EBL), also is called visible blood loss, intraoperative hemorrhage, and intraoperative blood loss; (3) surgical time, also called surgery duration and operation time; (4) length of hospital stay (LOS) also called duration of hospital stay, hospitalization stay, and hospitalization duration, can reflect the early postoperative recovery of patients; (5) fusion rate, percentage of cases exhibiting clinical or radiological fusion. Successful fusion is necessary for the long-term stability of the operative segment relies on the maintenance of surgical efficacy, which is based on a low incidence of complications and no need for reoperation.

2.3 | Literature Inclusion and Exclusion Criteria

The inclusion criteria were as follows: (1) patients with clinically confirmed LDDs, including degenerative lumbar stenosis, degenerative lumbar spondylolisthesis, and degenerative lumbar disc herniation; (2) interventions, including endoscopic TLIF/PLIF, MIS-TLIF, LLIF, or OLIF; (3) outcomes, including VAS-BP, VAS-LP, ODI, surgical time, intraoperative EBL, LOS, fusion rate and AEs; (4) single-level surgery; (5) internal fixation by bilateral pedicle screws or no internal fixation; and (6) a randomized controlled trial (RCT) or cohort study.

The exclusion criteria were as follows: (1) patients with infectious diseases, spinal trauma, deformity or tumors, a history of lumbar surgery, or acute cauda equina syndrome; (2) other surgical methods, such as anterior lumbar fusion, endoscopic lumbar discectomy, or posterior lumbar fusion; (3) special interventions, such as surgical robot assistance or O-arm navigation; (4) multilevel surgery; (5) lateral fixation, unilateral pedicle nail fixation, articular screw fixation, or other fixation methods; and (6) reviews, meta-analyses, cadaveric studies, experimental

TABLE 1 | Main differences among the six surgery types.

	ELIF		LLIF			
	BELIF	**UELIF**	**OLIF**	**X/DLIF**	**SA-LLIF**	**MIS-TLIF**
Patient position	Prone	Prone	Decubitus+Prone	Decubitus+Prone	Decubitus	Prone
Dispose of psoas	/	/	Avoid	Split	Avoid or split	/
Number of working channels	2	1	/	/	/	/
Invasion of spinal canal	Yes	Yes	No	No	No	Yes
Internal fixation	Bilateral PPS	Bilateral PPS	Bilateral PPS	Bilateral PPS	No internal fixation	Bilateral PS

Abbreviations: PPS: percutaneous pedicle screw; PS: pedicle screw.

articles, expert opinions, case reports, technical reports, case–control studies, or cross-sectional studies.

2.4 | Literature Search

The Embase, PubMed, Web of Science, and Cochrane Library databases were searched for comparative trials of TLIF or endoscopic lumbar fusion, and the full texts of relevant papers were manually reviewed. Studies were restricted to English, and the search period was restricted from 2004 to March 2024. The following search terms were used: "minimally invasive transforaminal lumbar interbody fusion" OR "MIS TLIF" OR "MI TLIF" OR "endoscopic lumbar interbody fusion" OR "Endo LIF" OR "Endo TLIF" OR "Endo PLIF" OR "endoscopy lumbar interbody fusion" OR "BELIF" OR "UBELIF" OR "ULIF" OR "lateral interbody fusion" OR "LLIF" OR "XLIF" OR "DLIF" OR "oblique interbody fusion" OR "OLIF" OR "transpsoas interbody fusion" OR "prepsoas interbody fusion".

2.5 | Literature Screening, Data Extraction, and Risk Assessment of Bias in the Included Studies

Two researchers, Zhao and Liu, independently screened, extracted, and cross-checked the relevant studies. Differences were resolved through discussion. The literature screening process was as follows: after review with the literature management software EndNote X9, the studies that did not meet the criteria according to the title or abstract were excluded. The full texts of the remaining studies were read, and the exclusion and inclusion criteria were applied to identify studies for inclusion. The extracted data included author name, time of publication, sample size, sex and age of patients, follow-up time, and observation outcomes. One researcher (Zhu) assessed the quality of the selected studies. The quality evaluation of the included RCTs was conducted according to the criteria in the Cochrane risk-of-bias tool, and the quality evaluation of the included cohort studies was performed via the Newcastle–Ottawa Scale (NOS) [11]; low-quality studies with scores below six points were excluded.

2.6 | Statistical Analysis

Treatment effects are expressed as the mean differences (MDs) and 95% confidence intervals (CIs) for continuous data or risk ratios (RRs) and 95% CIs for categorical data. Network meta-analysis (NMA) was performed via the frequentist model with a graph-theoretical method via the R (version 4.1.2) package net Meta (version 2.1-0). We used Stata version16.0 (Stata Corp, College Station, TX) to generate the network plots [12]. The estimator was based on weighted least-square regression with the Moore–Penrose pseudoinverse method [13]. We conducted pairwise meta-analysis with the DerSimonian–Laird random effects model to estimate the variance in heterogeneity between studies [14]. League tables of the relative treatment effects were used to visualize comparisons of network estimations. Global and local statistical heterogeneity was assessed with the generalized Cochran's Q test [15]. Local inconsistency of direct and indirect results was assessed with the node-splitting method for all comparison loops, and indirect results were derived from direct and network results via the back-calculation method [16, 17]. Funnel plots were used to identify publication bias and small-study effects for outcome measures that were reported in more than 10 studies.

3 | Results

3.1 | Literature Screening Results and the Characteristics and Quality of the Included Studies

Using the set search strategy, a total of 13,059 studies were identified, and 10,442 documents were obtained after the removal of duplicate studies. Eighty-six studies were selected after primary screening, and 35 studies that met the requirements were selected by reading the full texts [18–52] (Figure 2). The total number of patients in the included studies was 2899, including 252 who underwent BELIF, 525 who underwent UELIF, 1175 who underwent MIS-TLIF, 115 who underwent X/DLIF, 596 who underwent OLIF and 236 who underwent SA-LLIF. The quality evaluation results are shown in Supporting Information Files 1 and 2, and the median and quartile values of the NOS scores in the cohorts were 7 (8,7). The general features of the included studies are shown in Supporting Information File 3.

3.2 | Network Plot, Consistency Detection, Publication Bias, and Analysis Results

The network plot for each outcome measure in this study is shown in Figure 3. Among the outcome measures in this study, a large proportion of direct comparisons were between MIS-TLIF and all interventions except SA-LLIF, with fewer direct comparisons between the remaining interventions. SA-LLIF was directly compared with only OLIF and X/DLIF. The node-splitting method was used to test the four closed-loop outcome indicators, and the result was $p > 0.05$, indicating that the results of the direct and indirect comparisons were consistent; therefore, the possibility of inconsistency was small (Supporting Information File 4). The publication bias detected for EBL, VAS-LP score and operation time may have arisen because the included studies were mainly cohort studies, and the level of evidence was not high (Supporting Information File 5). The NMA prediction intervals are summarized in Figure 4.

3.3 | Primary Outcomes (Follow-Up Time of 12 Months or Longer)

VAS-LP score change: Data from 24 articles with 2237 participants were included in the analysis [18–29, 32–34, 37, 38, 40, 41, 43, 44, 46, 48, 51]. In the frequentist model, the mean difference in the reoperation and complication rates between any two interventions was nonsignificant. Heterogeneity analysis revealed no significant inconsistency ($Q = 0.17$; degrees of freedom = 4; $p = 0.9966$; Supporting Information File 5).

VAS-BP score change: Data from 24 articles with 2230 participants were included in the analysis [18–29, 32–34, 37, 38, 40, 41,

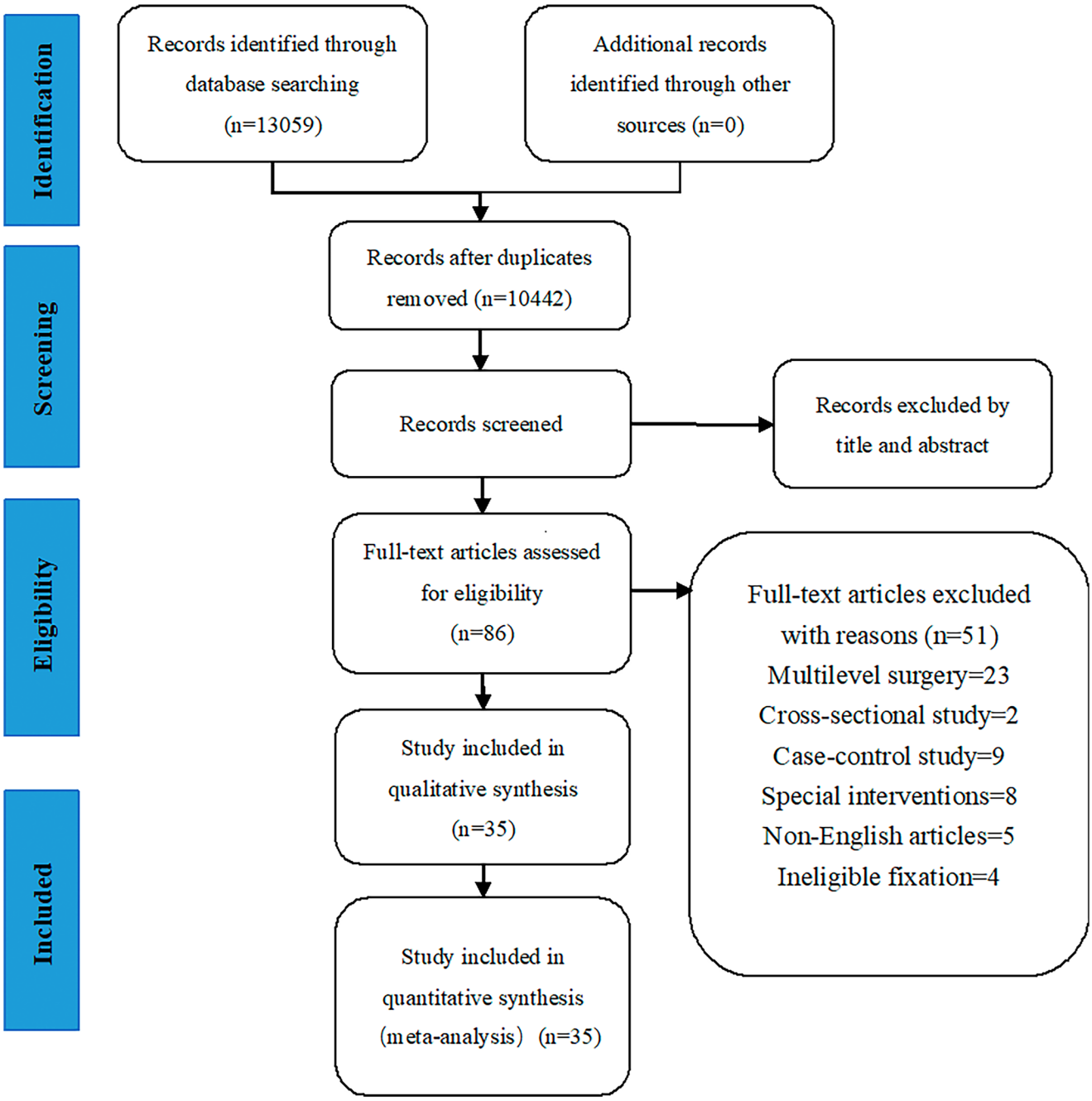

FIGURE 2 | Literature screening process.

43, 44, 46, 50, 51]. In the frequentist model, the mean difference in the reoperation and complication rates between any two interventions was nonsignificant. Heterogeneity analysis revealed no significant inconsistency ($Q = 1.00$; degrees of freedom = 4; $p = 0.9101$; Supporting Information File 6).

ODI change: Data from 25 articles with 2245 participants were included in the analysis [18–22, 24–29, 32–35, 37, 38, 40, 43, 46–48, 50–52]. In the frequentist model, the mean difference in the reoperation and complication rates between any two interventions was nonsignificant, except that the improvement in the ODI was greater in the OLIF group than in the UELIF group (MD: −1.93, 95% CI: −3.68–0.18; Figure 4). Heterogeneity analysis revealed no significant inconsistency ($Q = 6.24$; degrees of freedom = 4; $p = 0.1818$; Supporting Information File 6).

3.4 | Secondary Outcomes

AE: Data from 29 articles with 2465 participants were included in the analysis [18–20, 22–38, 40, 41, 43, 46, 48–52]. Except one study that did not describe AEs in detail [24], all AEs were counted according to the Clavien–Dindo surgical complication classification [53], and the summary results of the AEs are detailed in Supporting Information File 7. After excluding Clavien–Dindo grade I AEs (detected via imaging) without obvious clinical symptoms such as cage subsidence, cage migration,

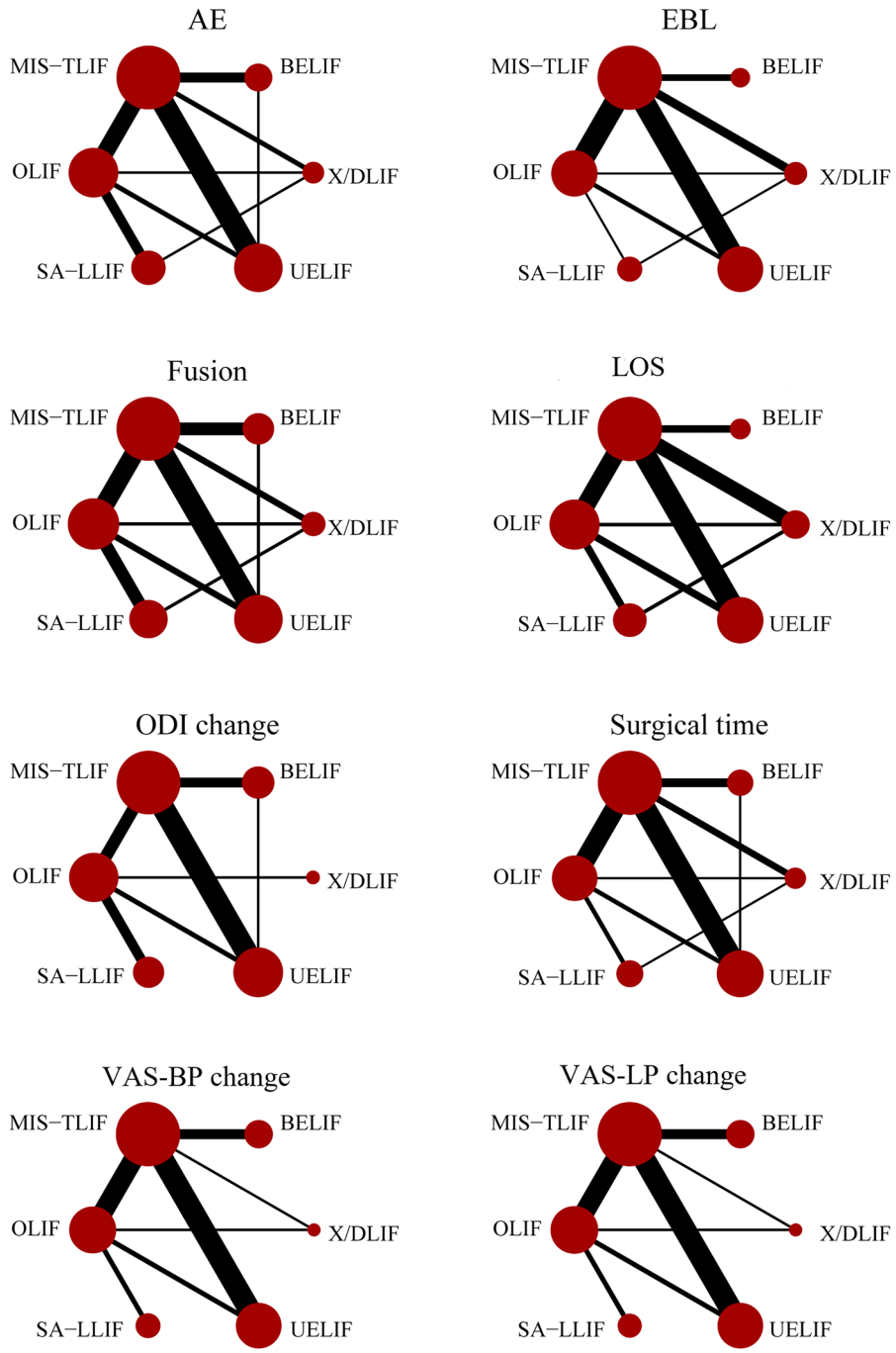

FIGURE 3 | The network plot for each outcome.

and endplate injury, in the frequentist model, the mean difference in the clinical complication rates between any two interventions was nonsignificant. Heterogeneity analysis revealed no significant inconsistency ($Q = 11.33$; degree of freedom = 9; $p = 0.2537$; Supporting Information File 6).

Surgical time: Data from 29 articles with 2413 participants were included in the analysis [18, 19, 22–35, 37–45, 47, 49, 51, 52]. In the frequentist model, the surgical time of SA-LLIF was significantly shorter than that of the other five procedures, and UELIF had a longer surgical time than MIS-TLIF and OLIF did (Figure 4). Heterogeneity analysis revealed no significant inconsistency ($Q = 6.77$; degree of freedom = 7; $p = 0.4533$; Supporting Information File 6).

LOS: Data from 19 articles with 1701 participants were included in the analysis [19, 20, 22–25, 29, 31, 33, 34, 36, 38, 39, 43, 45, 47, 49, 51, 52]. In the frequentist model, the LOS of SA-LLIF was significantly shorter than that of UELIF, X/DLIF, OLIF, and MIS-TLIF (Figure 4). Compared with MIS-TLIF, UELIF, and OLIF resulted in shorter hospitalization times (Figure 4). Heterogeneity analysis revealed no significant inconsistency ($Q = 4.81$; degree of freedom = 6; $p = 0.5682$; Supporting Information File 6).

Clinical Complication

BELIF	0.89 (0.39, 2.05)	0.65 (0.26, 1.59)	0.56 (0.21, 1.51)	0.91 (0.35, 2.33)	1.22 (0.36, 4.15)
-1.18(-89.01,86.66)	**MIS-TLIF**	0.72 (0.50, 1.04)	0.63 (0.37, 1.08)	1.01 (0.60, 1.71)	1.37 (0.56, 3.36)
71.55(-25.74,168.84)	**72.73(30.89,114.57)**	**OLIF**	0.87 (0.55, 1.39)	1.40 (0.77, 2.54)	1.89 (0.78, 4.61)
129.98(-9.68,269.64)	**131.16(22.58,239.74)**	58.43(-47.88,164.74)	**SA-LLIF**	1.60 (0.78, 3.28)	2.17 (0.90, 5.22)
80.77(-16.81,178.36)	**81.95(39.42,124.47)**	9.22(-45.89,64.32)	-49.21(-164.38,65.96)	**UELIF**	1.35 (0.49, 3.74)
52.50(-59.45,164.46)	53.68(-15.74,123.10)	-19.05(-93.90,55.81)	-77.48(-183.90,28.94)	-28.27(-108.78,52.25)	**X/DLIF**

EBL

BELIF	1.01(0.95,1.07)	0.93(0.87,1.00)	0.94(0.87,1.02)	1.00(0.94,1.07)	0.96(0.87,1.05)
-2.83(-5.16,-0.50)	**MIS-TLIF**	**0.93(0.89,0.97)**	**0.94(0.89,0.98)**	1.00(0.97,1.02)	0.95(0.88,1.02)
-0.68(-3.32,1.96)	**2.15(0.91,3.38)**	**OLIF**	1.01(0.98,1.03)	**1.07(1.02,1.12)**	1.02(0.96,1.10)
1.97(-1.19,5.13)	**4.80(2.66,6.93)**	**2.65(0.73,4.57)**	**SA-LLIF**	**1.06(1.01,1.12)**	1.02(0.95,1.09)
-0.47(-3.08,2.14)	**2.36(1.17,3.54)**	0.21(-1.29,1.72)	**-2.44(-4.77,-0.11)**	**UELIF**	0.96(0.89,1.03)
-1.95(-4.75,0.85)	0.88(-0.67,2.43)	-1.27(-3.00,0.47)	**-3.92(-6.13,-1.70)**	-1.48(-3.38,0.42)	**X/DLIF**

Fusion Rate

LOS

BELIF	-0.23(-1.89,1.43)	1.05(-1.22,3.32)	-0.42(-3.15,2.32)	-0.88(-2.67,0.91)	-2.16(-11.39,7.07)
24.18(-1.52,49.89)	**MIS-TLIF**	1.28(-0.35,2.91)	-0.18(-2.42,2.05)	-0.65(-1.75,0.45)	-1.93(-11.03,7.17)
30.81(-0.06,61.69)	6.63(-11.00,24.25)	**OLIF**	-1.46(-2.99,0.06)	**-1.93(-3.68,-0.18)**	-3.21(-12.16,5.74)
121.38(76.44,166.31)	**97.19(60.14,134.24)**	**90.57(55.95,125.18)**	**SA-LLIF**	-0.46(-2.78,1.86)	-1.75(-10.82,7.33)
-5.66(-34.18,22.85)	**-29.85(-46.10,-13.59)**	**-36.47(-58.59,-14.36)**	**-127.04(-166.66,-87.42)**	**UELIF**	-1.28(-10.40,7.84)
23.84(-15.89,63.56)	-0.35(-30.74,30.05)	-6.97(-38.84,24.90)	**-97.54(-136.60,-58.48)**	29.50(-4.53,63.53)	**X/DLIF**

ODI change

Surgical Time

BELIF	-0.04(-0.55,0.47)	0.25(-0.38,0.87)	0.20(-0.67,1.06)	0.21(-0.38,0.80)	-0.64(-1.68,0.41)
-0.13(-1.68,1.43)	**MIS-TLIF**	0.29(-0.07,0.64)	0.24(-0.46,0.93)	0.25(-0.05,0.54)	-0.60(-1.51,0.31)
-0.29(-2.17,1.60)	-0.16(-1.22,0.90)	**OLIF**	-0.05(-0.65,0.55)	-0.04(-0.46,0.39)	-0.88(-1.79,0.03)
0.46(-2.39,3.31)	0.58(-1.81,2.97)	0.74(-1.40,2.88)	**SA-LLIF**	0.01(-0.73,0.74)	-0.84(-1.93,0.25)
0.26(-1.57,2.08)	0.38(-0.57,1.34)	0.54(-0.75,1.84)	-0.20(-2.70,2.30)	**UELIF**	-0.84(-1.79,0.10)
-0.65(-3.79,2.49)	-0.52(-3.25,2.21)	-0.36(-3.09,2.37)	-1.10(-4.57,2.36)	-0.90(-3.76,1.96)	**X/DLIF**

VAS-BP change

VAS-LP change

FIGURE 4 | NMA prediction intervals.

EBL: Data from 28 articles with 2339 participants were included in the analysis [18–20, 23–27, 29–34, 36–47, 49, 51]. In the frequentist model, bleeding was significantly greater with MIS-TLIF than with OLIF, SA-LLIF, and UELIF (Figure 4). Heterogeneity analysis revealed no significant inconsistency ($Q = 3.42$; degree of freedom = 6; $p = 0.7549$; Supporting Information File 6).

Fusion rate: Data from 22 articles with 1920 participants were included in the analysis [19, 20, 22–24, 27–31, 33, 37, 38, 40, 41, 43, 46–48, 50–52]. In the frequentist model, the fusion of OLIF and SA-LLIF was significantly better than that of UELIF and MIS-TLIF. Heterogeneity analysis revealed no significant inconsistency ($Q = 6.77$; degree of freedom = 7; $p = 0.4527$; Supporting Information File 6).

4 | Discussion

4.1 | Clinical Outcomes

The primary finding of this study was the difference in the long-term improvement in pain and dysfunction in patients with LDD caused by these minimally invasive lumbar interbody fusion procedures. This NMA did not reveal any significant differences between the six procedures in terms of improvements in low back pain, leg pain, or dysfunction, suggesting that minimally invasive lumbar interbody fusion can provide equivalent clinical symptomatic improvement regardless of whether decompression is direct or indirect, provided that the indications are met.

In terms of early outcomes, such as length of hospitalization and surgical time, SA-LLIF has significant advantages over other procedures. SA-LLIF inherently has a shorter operative time, and the hospitalization of patients who underwent SA-LLIF may have been shorter because eliminating internal fixation implantation avoids intraoperative trauma to the patient's back, which allows clinical benefits to be evident sooner. However, we did not find any significant difference in intraoperative blood loss between SA-LLIF and the other procedures except for MIS-TLIF. In fact, intraoperative bleeding in SA-LLIF was significantly lower than that in OLIF and X/DLIF in the included studies [49, 52]; this finding may have arisen because direct evidence that could be included in the analysis was insufficient. Although the need for internal fixation in LLIF remains controversial, the combined results of the present study and previous reports show that SA-LLIF has a clear advantage in terms of early results and is suitable for patients with poor tolerance to surgery and anesthesia. For lumbar interbody fusion requiring internal fixation, the early results are similar irrespective of the use of an endoscopic posterolateral or lateral approach. Nevertheless, both approaches result in faster symptom relief than does open lumbar fusion.

4.2 | Fusion Rate

Observation of intervertebral bridging trabeculae via computed tomography (CT) is the most definitive method for determining fusion [54]; however, the success of fusion can also be judged clinically on the basis of the segmental movement of the fused level less than 4° on flexion–extension dynamic radiographs and the absence of mechanical low back pain [20]. This study prioritized CT fusion, but different definitions of fusion in various articles inevitably weaken the comparability of the results. The results confirmed that the fusion rate was greater for lateral fusions than for posterolateral fusions. The reason for this difference is that large cages are often implanted via lateral fusion to open the intervertebral space for indirect decompression, resulting in a more stable intervertebral space and a larger bone grafting area.

4.3 | Complications

While the incidence of clinical complications did not significantly differ, the main complications did significantly differ among the procedures. Common complications of ELIF include transient lower extremity discomfort and dural tears, similar to those of the traditional posterolateral approach, but cage subsidence and endplate injury have not been reported. Unlike conventional procedures, such as MIS-TLIF, ELIF enables endplate preparation to be visualized directly through the endoscope, which helps to avoid endplate fracture, cage subsidence and fusion failure due to endplate overhandling [20, 55]. Although this procedure was not associated with entry into the spinal canal or nerve root injury, studies of LLIF still identified numerous symptoms of psoas and lumbar plexus injuries, such as numbness and weakness in the lower extremities. Although OLIF does not directly damage the psoas, prepsoas methods, which are performed when the cross-sectional area of the psoas is too large, can lead to excessive stretching of the psoas [56]. In addition, sympathetic chain and segmental artery injuries are commonly observed with OLIF procedures. In postoperative follow-up imaging observations, lateral fusion often involves cage subsidence or replacement, and an operation without internal fixation support increases the possibility of such a phenomenon. Although these kinds of AEs usually do not result in obvious clinical symptoms, secondary surgery is necessary in a few serious cases, which places an additional burden on the patient. Therefore, severe obesity and osteoporosis lead patients to be at greater risk of indirect decompression failure due to cage subsidence and are often considered surgical contraindications for lateral fusion. For patients with SA-LLIF in particular, the choice of surgical modality needs to be carefully evaluated in conjunction with body mass index (BMI) and bone mineral density (BMD).

4.4 | Limitations of New Surgical Techniques

Despite current technological advances in minimally invasive surgery of the spine, such as ELIF and LLIF, replacing traditional procedures remains challenging, in part owing to the longer learning curve of the new approaches. The technique itself requires the operator to master skills such as hemostasis, orientation, and correct recognition of anatomical structures and manipulation of instruments in narrow working channels, and whether the operator reaches the plateau of the learning curve significantly influences the incidence of complications. Second, indications for these surgeries are limited. Ensuring safety and decompression during ELIF is difficult in the face of the intervertebral space, Kambin's triangle, and patients with severe spinal stenosis. LLIF is also not suitable for treating spinal stenosis because of the free nucleus pulposus, dural occupancy, ossification of the posterior longitudinal ligament, calcification of the ligamentum flavum, facet joint synostosis and fusion [57, 58], and it cannot be used to treat lumbar spondylolisthesis of Grade III or greater [59]. In addition, fluoroscopy for multiple stages of preoperative positioning, manipulator position confirmation, interbody fusion position confirmation, and PPS implantation procedures increases the patient's radiation exposure time.

4.5 | Comparison With Previous Studies

This study is the first to compare SA-LLIF as an independent operation type with ELIF and the first ELIF-related NMA to limit

the scope of the study to single-segment surgery. Owing to the lack of direct evidence, comparisons between ELIF and LLIF rely on indirect comparisons that can be provided via NMA, and only one NMA for these two procedures has been published to date. Our study is consistent with Li's findings [10] in terms of pain relief by procedure, whereas the significant differences in ODIs, complications, and fusion rates in our study were much less pronounced, and OLIF was more significantly different from other procedures than XLIF was; however, this difference may be due to the low number of included X/DLIF studies. In the currently searchable literature, ELIF is most often compared with MIS-TLIF. Recent meta-analyses have shown that, compared with minimally invasive non-ELIF procedures, ELIF results in reduced blood loss, a shorter ambulation time, and a shorter hospital stay, but the surgical time is longer [60]. An RCT meta-analysis performed by Wu [61] revealed that MIS-TLIF resulted in greater improvement in the ODI than endoscopic transforaminal lumbar interbody fusion (Endo-TLIF), which is consistent with our previous findings [8]. The main difference between UELIF and BELIF is the duration of surgery [35], which was indirectly reflected in other studies [62, 63], but this difference was not significant in our study.

4.6 | Strengths and Limitations of Our Study

Evidence-based medical studies comparing LLIF and ELIF have been reported, but this study is the first to limit the scope of surgery to a single segment, which reduces implementation bias resulting from the inclusion of meta-analyses, thus improving the credibility of the results. In addition, this study was the first to compare the clinical efficacy of SA-LLIF as an independent intervention with that of endoscopic posterolateral fusion surgery and reveal its advantages, such minimal intraoperative trauma and early recovery, over other minimally invasive fusion procedures. However, our study had several limitations. First, limitations were placed on the inclusion criteria, and the paucity of studies related to some of the procedures resulted in a quantitative and qualitatively limited sample size for this study. Although we attempted to eliminate heterogeneity due to differences in the number of segments operated on by restricting the studies to those with single-segment surgeries, the smaller sample size and the resulting failure to form reliable loops for some of the results may have affected the statistical robustness of the study results. Second, some procedures, such as ELIF, are relatively new technologies, and differences in surgeons' experience with these procedures may affect certain outcomes, such as operative time. The clinical impact of each of the newer procedures will continue to be observed. Third, the lack of relevant studies precluded a statistical analysis of outcomes, such as ambulation time, fluoroscopy time and Japanese Orthopedic Association score.

5 | Conclusion

Our study revealed that both LLIF with indirect decompression and ELIF with direct decompression are equally effective in relieving pain and reducing the likelihood of disability in patients with LDD. SA-LLIF has significant advantages in terms of early efficacy, such as operative time and hospitalization, but the prevalence of cage subsidence and the possible risk of reoperation are reminders of the need to be rigorous about surgical indications before this type of procedure can be performed. In addition, OLIF and SA-LLIF have higher fusion success rates than UELIF does, suggesting that researchers focusing on ELIF can improve the fusion rate and reduce the risk of recurrence and need for repair surgery by developing a larger cage. However, more relevant research is needed to obtain more reliable results.

Author Contributions

Xijian Hu: study design, writing – background and discussion, translation. **Lei Yan:** study design, statistical analysis. **Jing Chai:** writing – background and discussion. **Xiaofeng Zhao:** literature screening. **Haifeng Liu:** literature screening. **Jinhuai Zhu:** risk assessment of bias in included studies. **Huo Chai:** risk assessment of bias in included studies. **Yibo Zhao:** article content review and revision. **Bin Zhao:** article content review and revision.

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The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.